Chapter 6

FM Circuits

Topics Covered

- 6-1: Frequency Modulators
- 6-2: Frequency Demodulators

Objectives

You should be able to:

- Explain the operation of an FM modulators and demodulators.
- Compare and contrast; FM using crystal oscillator circuit with FM using varactors.
- Analyze the resonant frequency from the designed oscillator or tuned circuit.
- Design the FM modulator and demodulator for the specific requirement.

6-1: Frequency Modulators

- There are many circuits used to produce FM signals and can be divided into two:
  - direct circuits and
  - phase modulation circuits.
- A **frequency modulator** is a circuit that varies **carrier frequency** in accordance with the modulating signal.
- The carrier is generated by *LC* or crystal oscillator circuits.

6-1: Frequency Modulators

- In *LC* oscillators, the carrier frequency can be changed by varying either the inductance or capacitance.
- The idea is to find a circuit or component that converts a modulating voltage to a corresponding change in capacitance or inductance.
- In crystal oscillators, the frequency is fixed by the crystal.
- Connecting an external capacitor to the crystal allows minor variations in operating frequency to be obtained.

6-1: Frequency Modulators

- Again the objective is to find a circuit or component whose capacitance will change in response to the modulating signal.
- The component most frequently used for this purpose is a varactor.
- Also known as a
  - voltage variable capacitor,
  - variable capacitance diode
  - varicap.
- A **varactor** is used to change oscillator frequencies

6-1: Frequency Modulators

Varactor Operation

- A junction diode is created when P- and N-type semiconductors are formed during the manufacturing process.
- A **depletion region,** where there are no free carriers, holes, or electrons, is formed in the process.
- This region acts like a thin insulator that prevents current from flowing through the device.
- A forward bias will cause the diode to conduct.
- A reverse bias will prevent current flow.

6-1: Frequency Modulators

Varactor Operation

- A reverse-biased diode acts like a small capacitor.
- The P- and N-type materials act as the two plates of the capacitor.
- The depletion region acts as the dielectric material.
- The width of the depletion layer determines the width of the dielectric and, therefore the amount of capacitance.
- All diodes exhibit variable capacitance.
- Varactors are designed to optimize this characteristic.

6-1: Frequency Modulators

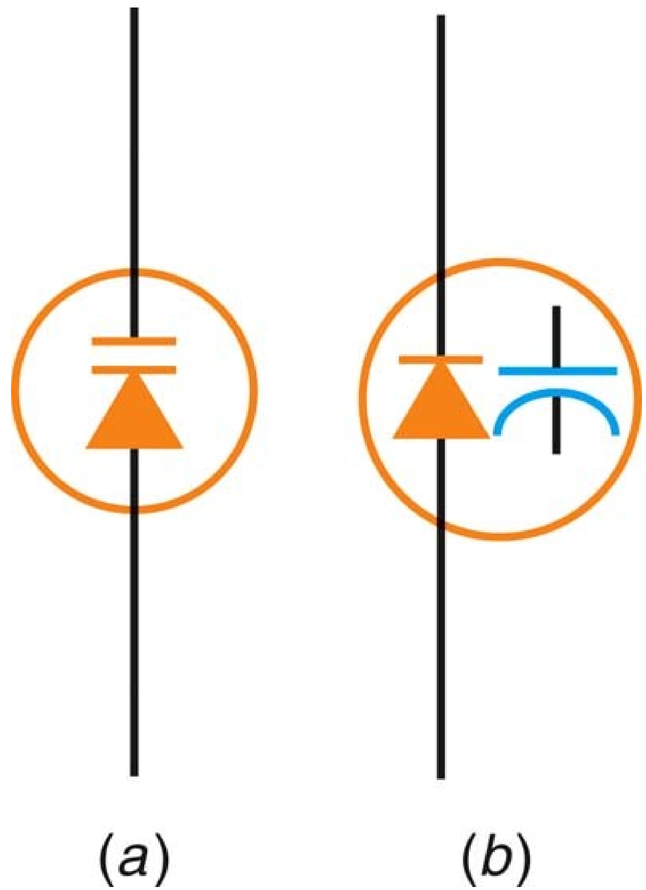

Figure 6-2: Schematic symbols of a varactor diode.

6-1: Frequency Modulators

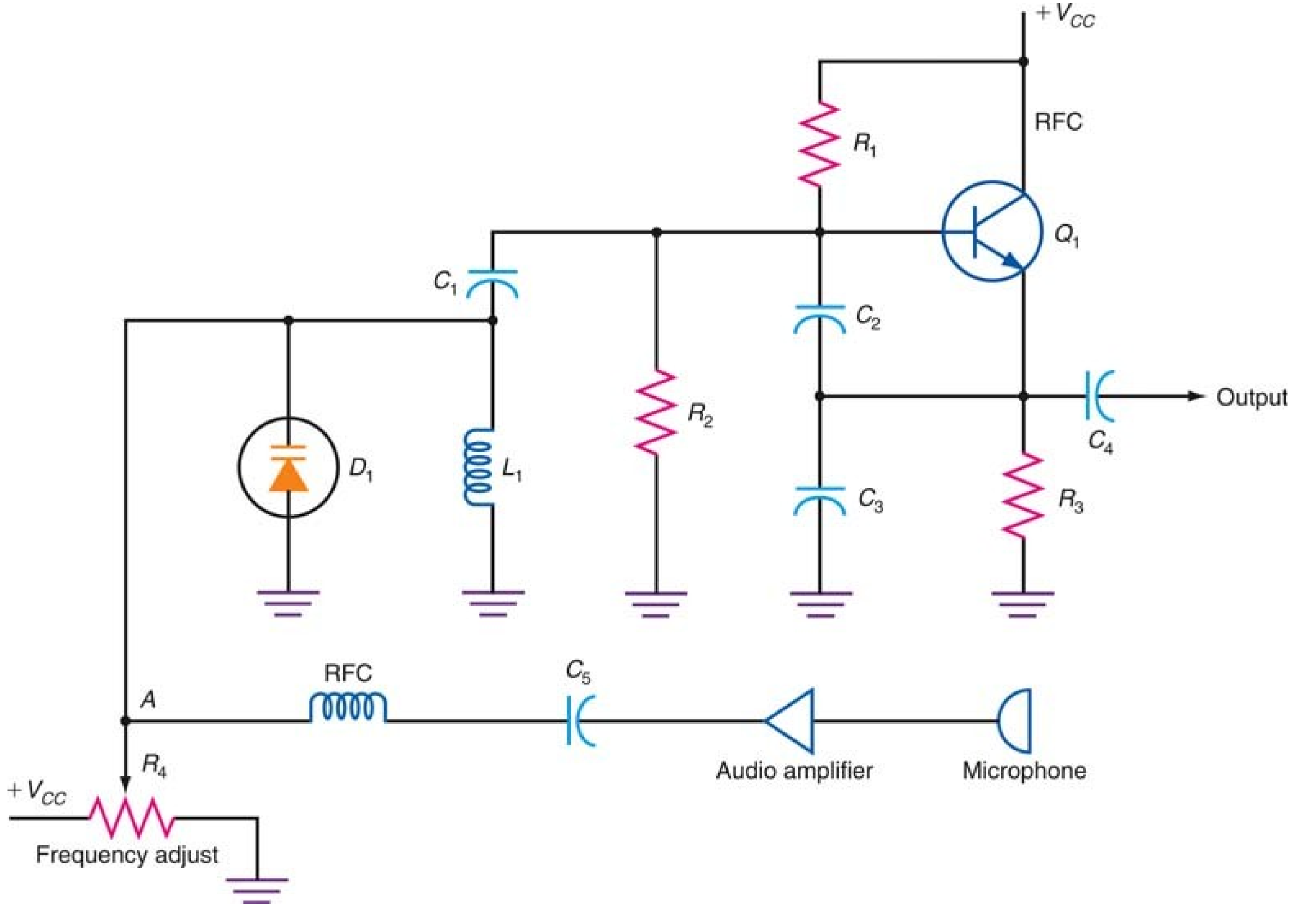

Figure 6-4: A direct-frequency-modulated carrier oscillator using a varactor diode.

6-1: Frequency Modulators

Varactor Modulator

- In Figure 6-4, the capacitance of varactor diode D_1 and L_1 form the parallel tuned circuit of the oscillator.
- The value of C_1 is made very large so its reactance is very low.
- C_1 connects the tuned circuit to the oscillator and blocks the dc bias on the base of Q_1 from being shorted to ground through L_1.
- The values of L_1 and D_1 fix the center carrier frequency.
- The modulating signal varies the effective voltage applied to D_1 and its capacitance varies.

6-1: Frequency Modulators

Varactor Modulator

- Most *LC* oscillators are not stable enough to provide a carrier signal.
- The frequency of *LC* oscillators will vary with temperature changes, variations in circuit voltage, and other factors.
- As a result, crystal oscillators are normally used to set carrier frequency.

Example

- The value of capacitance of a varactor is 40pF. This varactor will be parallel with a fixed 20pF capacitor. Calculate the value of inductance should be used to resonate this combination to 5.5 MHz in an oscillator?

6-1: Frequency Modulators

Frequency-Modulating a Crystal Oscillator

- Crystal oscillators provide highly accurate carrier frequencies and their stability is superior to *LC* oscillators.
- The frequency of a crystal oscillator can be varied by changing the value of capacitance in series or parallel with the crystal.
- By making the series capacitance a varactor diode, frequency modulation can be achieved.
- The modulating signal is applied to the varactor diode which changes the oscillator frequency.

6-1: Frequency Modulators

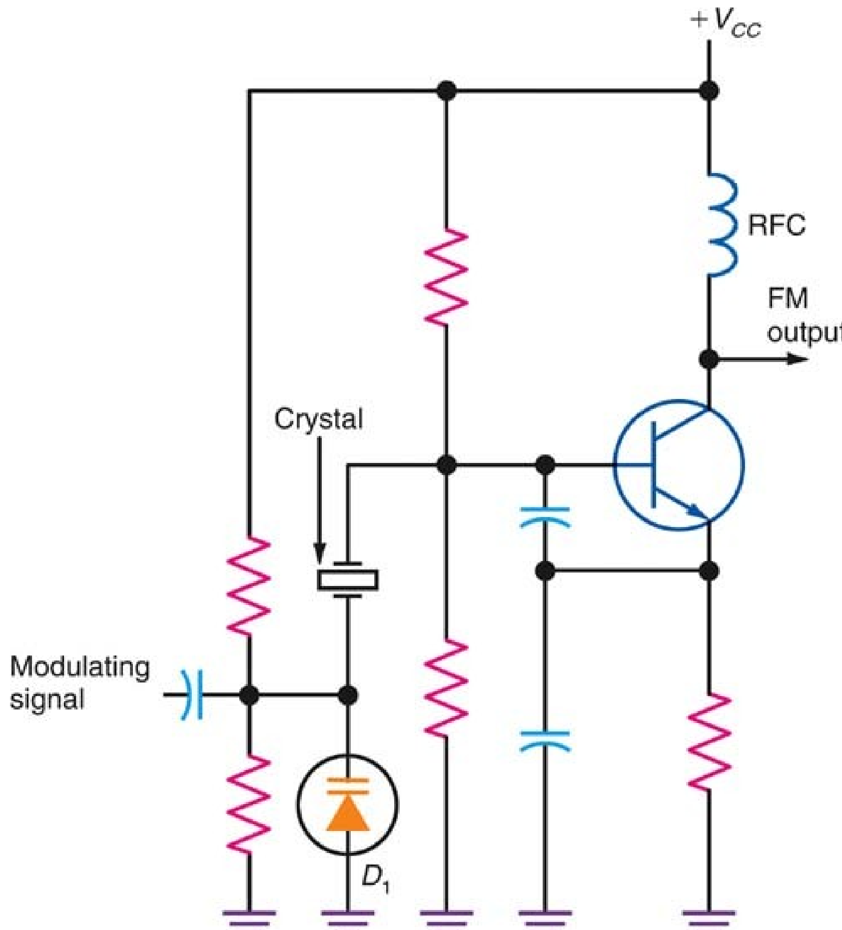

Figure 6-5: Frequency modulation of a crystal oscillator with a VVC.

6-1: Frequency Modulators

Reactance Modulator

- A **reactance modulator** is a circuit that uses a transistor amplifier that acts like either a variable capacitor or an inductor.
- When the circuit is connected across the tuned circuit of an oscillator, the oscillator frequency can be varied by applying the modulating signal to the amplifier.
- Reactance modulators can <u>**produce frequency deviation over a wide range**</u>.
- Reactance modulators are <u>**highly linear, so distortion is minimal.**</u>

6-1: Frequency Modulators

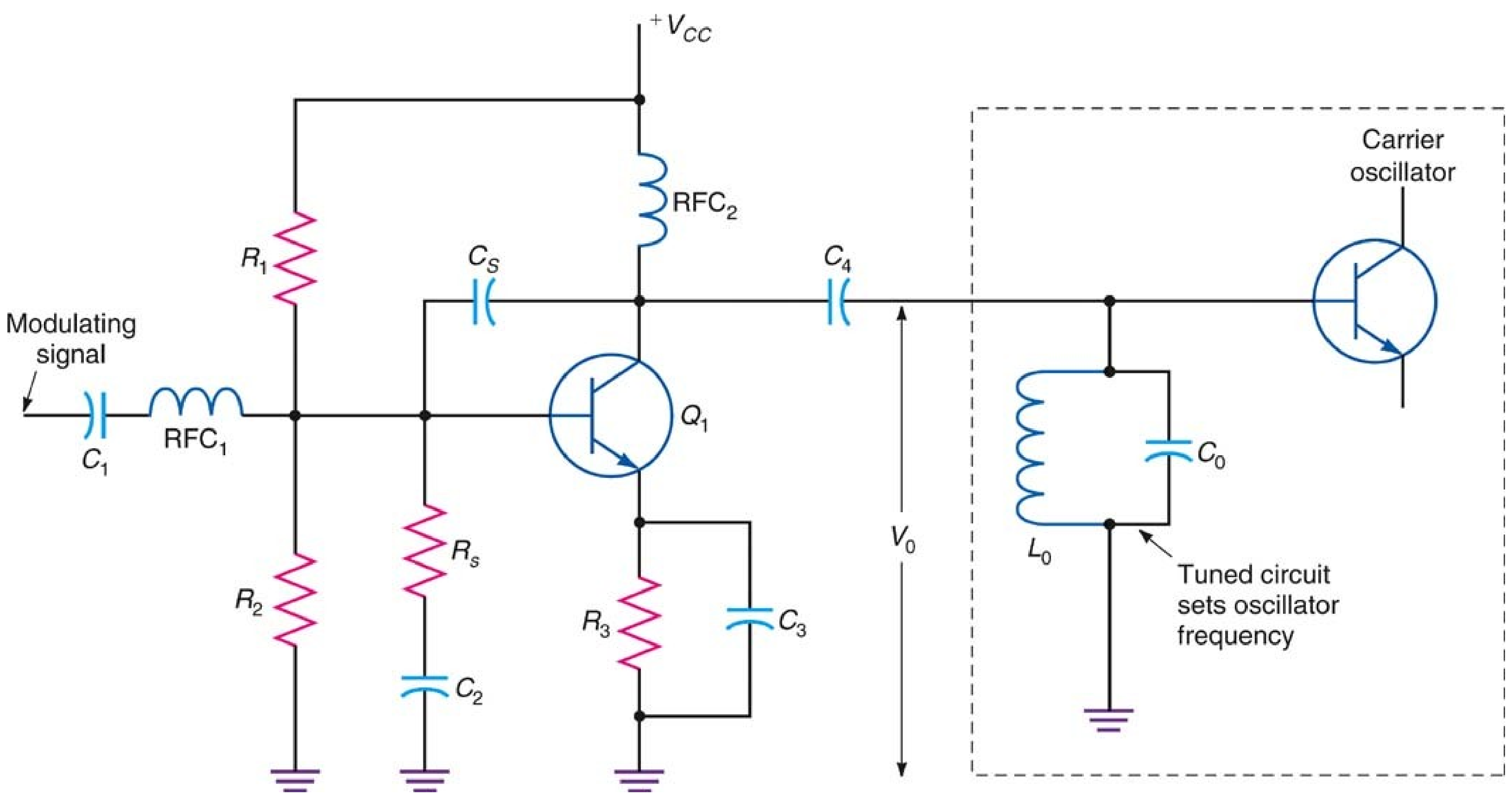

Figure 6-10: A reactance modulator.

6-1: Frequency Modulators

Reactance Modulator-circuit operation.

- Modulating signal is applied to the modulator through C1 and RFC1.
- Audio modulating signal varies the base voltage and current of Q1 according to the intelligence to be transmitted.
- The collector current amplitude varies, the phase-shift angle change respect to the oscillator voltage, which is interpreted by the oscillator as a change in capacitance.
- Increase capacitance lower the frequency and vice versa, so the circuit produces direct FM.

6-2: Frequency Demodulators

- Any circuit that will convert a frequency variation in the carrier back into a proportional voltage variation can be used to demodulate or detect FM signals.
- Circuits used to recover the original modulating signal from an FM transmission are called:
  - Demodulators
  - Detectors
  - Discriminators

6-2: Frequency Demodulators

Slope Detector

- The **slope detector** makes use of a tuned circuit and a diode detector to convert frequency variations into voltage variations.
- The main difficulty with slope detectors lies in tuning them.

6-2: Frequency Demodulators

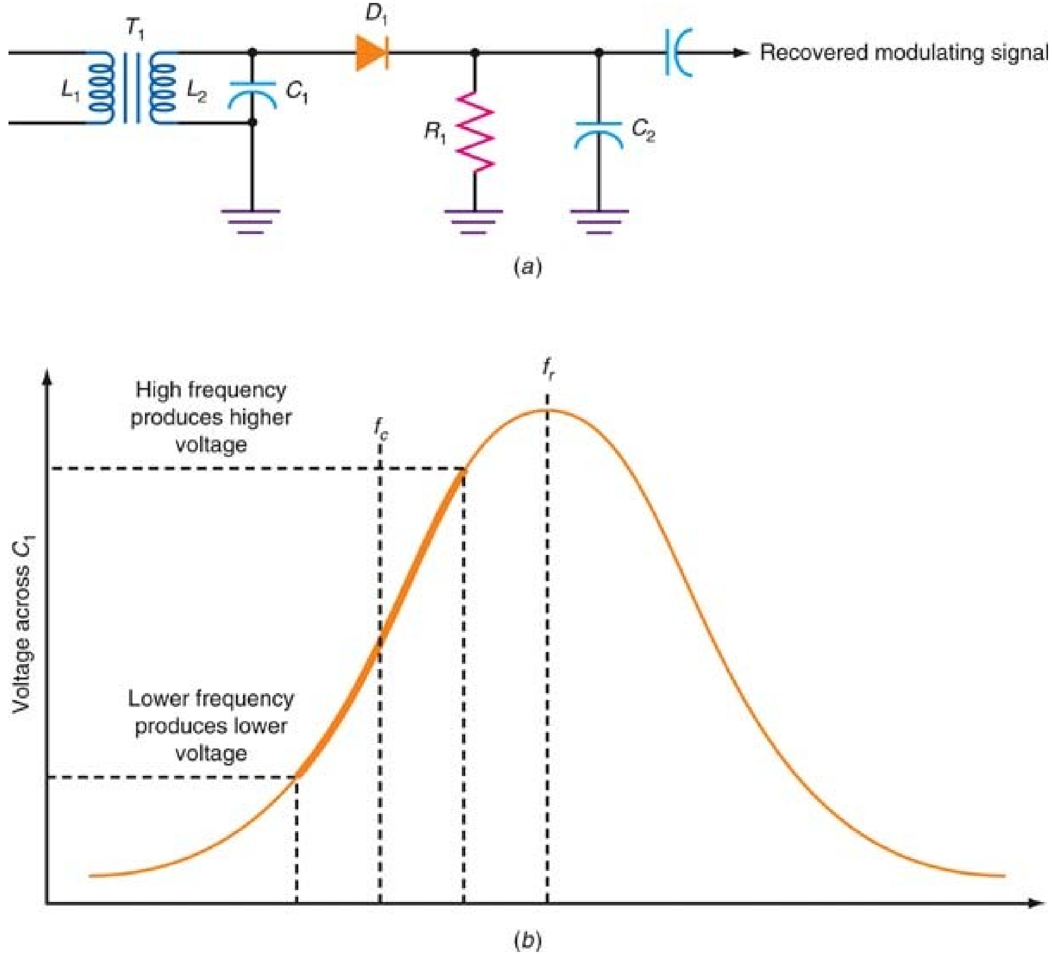

Figure 6-16: Slope detector operation.

6-2: Frequency Demodulators

Pulse-Averaging Discriminators

- A **pulse-averaging discriminator** uses a zero crossing detector, a one shot multivibrator and a low-pass filter in order to recover the original modulating signal.
- The pulse-averaging discriminator is a very high-quality frequency demodulator.
- Originally this discriminator was limited to expensive telemetry and industrial control applications.
- With availability of low-cost ICs, this discriminator is used in many electronic products.

6-2: Frequency Demodulators

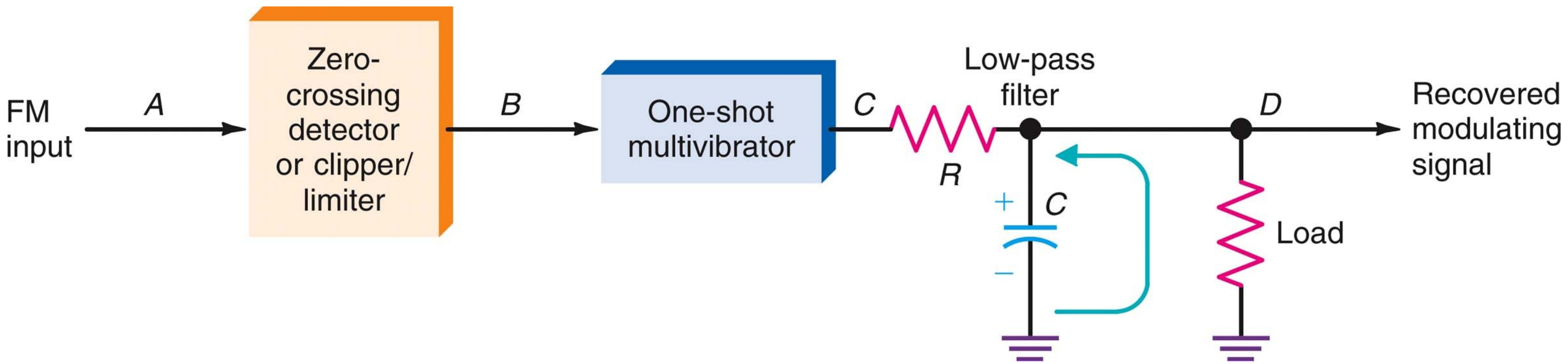

Figure 6-17: Pulse-averaging discriminator.

6-2: Frequency Demodulators

Quadrature Detector

- The **quadrature detector** is probably the single most widely used FM demodulator.
- The quadrature detector is primarily used in TV demodulation.
- This detector is used in some FM radio stations.
- The quadrature detector uses a phase-shift circuit to produce a phase shift of 90 degrees at the unmodulated carrier frequency.

6-2: Frequency Demodulators

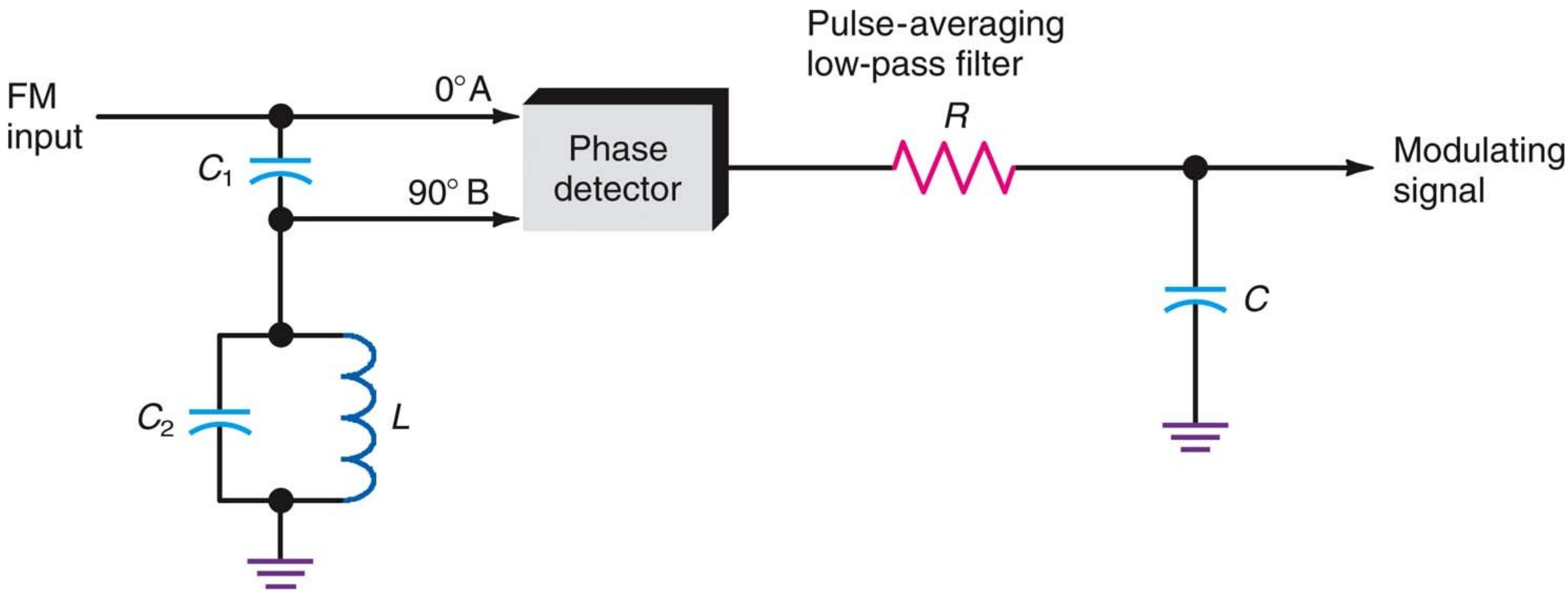

Figure 6-19: A quadrature FM detector.

Quadrature Detector

- The FM signal applied through the small capacitor C1 to the parallel tuned circuit, which is adjusted to resonate at the center freq.
- At resonance, the tuned circuit appears as high value of pure resistance.
- The small capacitor has a very high reactant compared to the tuned circuit impedance.

Quadrature Detector

- Thus the output across the tuned circuit at the carrier freq is very close to 90^0 and leads the input.
- When the FM occurs, the carrier freq deviates above and below the resonant freq of the tuned circuit, resulting an increasing or a decreasing amount of phase shift between the input and output.

6-2: Frequency Demodulators

Phase-Locked Loops

- A phase-locked loop (PLL) is a frequency- or phase-sensitive feedback control circuit used in frequency demodulation, frequency synthesizers, and various filtering and signal-detection applications. PLLs have three basic elements. They are:
  - Phase detector
  - Low-pass filter
  - Voltage-controlled oscillator

6-2: Frequency Demodulators

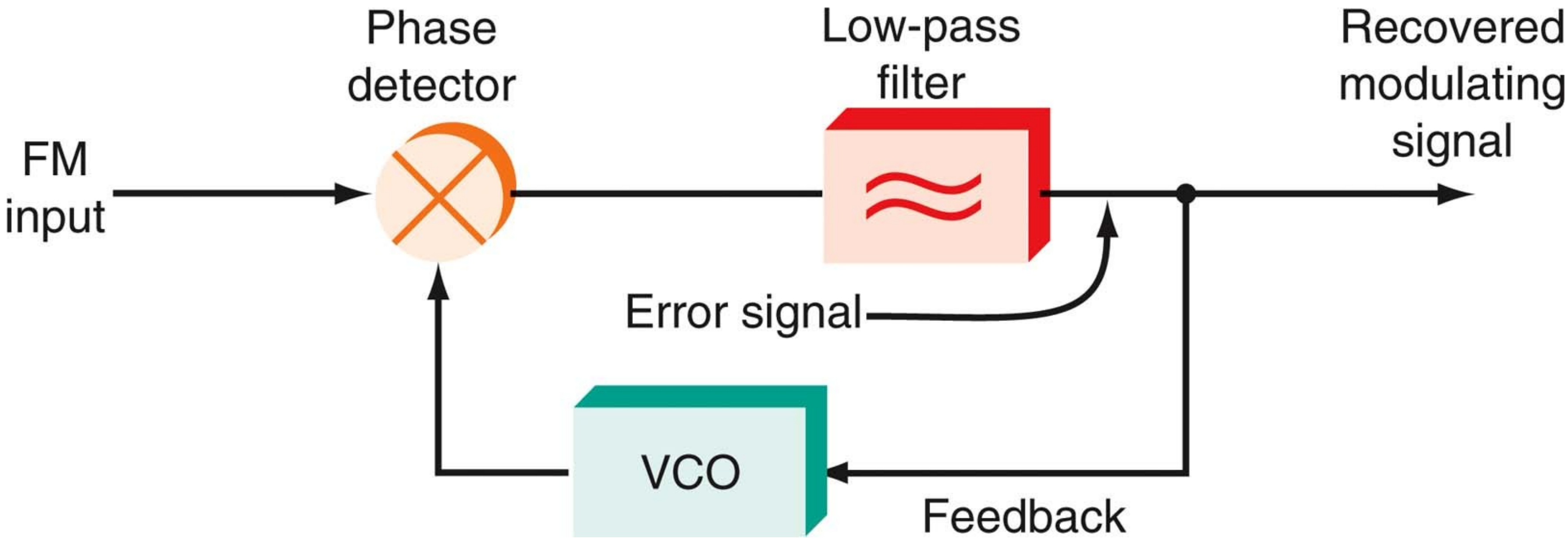

Figure 6-21: Block diagram of a PLL.

6-2: Frequency Demodulators

Phase-Locked Loops

- The primary job of the phase detector is to compare the two input signals and generate an output signal that, when filtered, will control the VCO.
- If there is a phase or frequency difference between the FM input and VCO signals, the phase detector output varies in proportion to the difference.
- The filtered output adjusts the VCO frequency in an attempt to correct for the original frequency or phase difference.

6-2: Frequency Demodulators

Phase-Locked Loops

- This dc control voltage, called the **error signal,** is also the feedback in this circuit.
- When no input signal is applied, the phase detector and low-pass filter outputs are zero.
- The VCO then operates at what is called the **free-running frequency,** its normal operating frequency as determined by internal frequency-determining components.

Exercise PECS-pp197

- A parallel tuned circuit in an oscillator consists of a 40uH inductor in parallel with a 330pF cap. A varactor with capacitance of 50pF is connected in parallel with the circuit. What is the resonant frequency of the tuned circuit and the oscillator operating frequency.

- If the varactor capacitance of the circuit above is decreased to 25pF,
  - How does the frequency change?
  - What is the new resonant frequency.

Exercise PECS-pp197

- A 565 IC PLL has an external resistor R1 of 1.2 kohm and a capacitor C1 of 560pF. The power supply is 10V.
  - What is the free-running frequency
  - Define the lock range.
  - What is the total lock range for this PLL circuit.